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SUBMERGED-ARC STRIP OVERLAY WELDING OF 2.25 Cr - 1 Mo STEEL

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WELDING SECTION

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PHYSICAL METALLURGY RESEARCH LABORATORIES
REPORT ERP/PMRL 83-18(TR)

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by

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ABSTRACT

An attempt has been made to overlay 2.25 Cr - 1 Mo steel with 308L and 347 stainless steels by using a submerged-arc strip overlay process. A buffer layer of 309L stainless steel was used to give a low carbon value. Stainless steel strips measuring 60 x 0.5 mm were used and the deposited beads were found to be sound and defect free. The microstructures and mechanical properties of the overlayed joints were assessed and correlated for both the 'as welded' and 'stress relieved' conditions. Chemical compositions of the overlays were determined by microprobe analysis and wet analysis.

LABORATOIRES DE RECHERCHE EN MÉTALLURGIE PHYSIQUE
RAPPORT PRE/LRMP 83-18(TR)

SOUDAGE À L'ARC SOUS FLUX AVEC FEUILLARD DE RECOUVREMENT D'ACIER 2,25 Cr - 1 Mo

par

R.S. Chandel et R.F. Orr

RÉSUMÉ

On a entrepris le recouvrement de l'acier inoxydable 2,25 Cr - 1 Mo avec des aciers inoxydables 308L et 347 au moyen du soudage à l'arc sous flux avec feuillard de recouvrement. On a employé une couche protectrice d'acier inoxydable 309L afin de procurer une valeur basse de carbone. On a utilisé des bandes d'acier inoxydable qui mesuraient 60 x 0,5 mm dont les cordons résultants se sont avérés sains et sans défauts. Ensuite on a évalué les microstructures et les propriétés mécaniques des joints recouverts, les mettant en corrélation avec les conditions brutes de soudage et après recruit de détente. On a déterminé les compositions chimiques des joints recouverts par microanalyse et par analyse à voie humide.

INTRODUCTION

The work reported here constitutes a part of the on-going programme on pressure vessels. Previous work has shown that 2.25 Cr - 1 Mo steel, which is the most popular material for the fabrication of thick-walled pressure vessels, can be clad successfully with austenitic stainless steels by using the submerged-arc strip overlay process (1).

In order to perform satisfactorily in service a stainless steel overlay is required to have the following characteristics:

(i) A guaranteed minimum thickness of overlay

(ii) A minimum thickness of cladding within the specification for the stainless steel

(iii) A suitable deposited microstructure and satisfactory mechanical properties

(iv) Complete fusion between base metal and overlay

(v) A finely rippled bead surface, free from cracks, porosity, and slag inclusions

The aim of the present work was to assess the above properties of the overlay joints in both 'as welded' and 'stress relieved' conditions.

EXPERIMENTAL TECHNIQUES

MATERIAL

The experimental base material was a 2.25 Cr - 1 Mo (SA-387 Grade 22 class 2) steel which is generally used for the fabrication of petrochemical reactor vessels because of its strength, toughness and creep resistance. The plate was 37.6 mm thick and was supplied in the normalized and tempered condition. The chemical composition of this base plate is given in Table 1 and its microstructure is shown in Fig. 1. The plate was cut into 305 x 406 mm pieces and the surfaces were cleaned to remove dirt and oxides.

The weld deposits were made by using 60 mm x 0.5 mm strips of 309, 308, and 347 stainless steels. The chemical compositions of these strips are given in Table 1. A matching neutral and non-compensating type of flux was used for welding. Strips and flux were manufactured and supplied by Sandvik.

WELDING

A Lincoln SA-800 submerged-arc unit was used in conjunction with the Sandvik welding head suitable for strip widths of 60 mm to 120 mm. The power source was a variable potential DC generator.

The plates to be overlaid were tack welded on all four sides to prevent distortion. The flux was baked at 260°C for 2 h before use to remove moisture. Before welding started, the strip was cut at an angle of 20° to facilitate the arc starting and was lowered to about 35 mm from the plate. Throughout the work the strip was held at 90° to the plate; the electrode was made positive. The normal length of the deposit was 355 mm.

The first layer was deposited by using 309L stainless steel strip. In order to get a flat weld deposit and a smooth tie-in between beads, an overlap of 5 mm was used. A second layer of 308L or 347 stainless steel was deposited over the previously laid first layer of 309L stainless steel. The second layer was not placed directly over the first layer, instead it was offset such that the centre of this layer was 10 mm away from the centre of the first layer. The welding parameters were taken from the previous work (1) and are listed in Table 2.

POST-WELD HEAT TREATMENT

Although some of the overlaid plates were retained for further investigation, others were given a post weld heat treatment in an argon atmosphere. The heat treating cycle was in accordance with ASME Division I UCS-56 and consisted of heating the plates to 677°C (1250°F) and holding them at that temperature for 2 h. The heating and cooling rates were 56°C/h (100°F/h).

BEND TESTS

Side bend test specimens were cut from both 'as welded' and 'stress relieved' plates. From each plate four specimens (two perpendicular to and two longitudinal to the direction of welding) measuring 9.5 x 50.8 x 152.4 mm were cut. The specimens were cut in such a way that they contained the full thickness of the overlay. These specimens were then subjected to 180° bending by using a 38 mm mandrel.

MICROHARDNESS SURVEY

Microhardness measurements were carried out with a Tukon tester on specimens cut in a direction perpendicular to the weld. Several hardness

impressions were made perpendicular to the fusion line. Measurements were made in the base metal, HAZ, fusion line and overlays using an impression load of 500 g.

METALLOGRAPHY

Metallographic techniques were used to reveal the microstructures in the parent metal, HAZ, fusion line, and clad layers. The microstructures in the base plate and HAZ were revealed by a 2% nital etch. An electrolytic etch with a 2% chromic solution revealed the ferrite and carbides in the overlay. The ferrite contents of the overlays were determined by a Magne-gauge.

CHEMICAL ANALYSIS

The chemical composition of the second layer of overlay was determined by conventional wet analysis as per QW 462.5 of ASME IX. To investigate the constitution of the fusion boundaries between the base plate and the first weld overlay and between the first and second layers of overlay an electron microprobe analyser was used.

RESULTS AND DISCUSSION

GENERAL BEAD CHARACTERISTICS

The deposited weld overlay beads were smooth with fine ripples. The slag was easily detached and left no impressions on the surface. The tying-in was such that the junction had a smooth bead contour. The total thickness of the overlay was 10-11 mm and both fusion lines were parallel as shown in Fig. 2. The dilution between base metal and 309L overlay was about 15%.

Although dye penetration and other NDE methods were not used to detect cracks, porosity, and slag inclusions, extensive macroscopic examination of surfaces and various sections showed that the deposits were sound and defect free.

When subjected to the guided bend test the test specimens were bent easily by 180° both in 'as welded' and 'stress relieved' conditions without cracking. In most cases some plastic deformation was observed in the form of wrinkling in the overlay portion of the specimen indicating that the joints were fully ductile.

MICROSTRUCTURE

Figure 4 shows the microstructures of base metal, HAZ, fusion line and overlay regions. The base material contains tempered bainite and ferrite. In the 'as welded' condition the HAZ microstructure consists of varying amounts of bainite and ferrite with an increasing amount of bainite closer to the fusion line. The increase in bainite is consistent with the increased peak temperature as the fusion line is approached. This variation continues up to the point at which the A_3 temperature is reached. At that point a practically fully bainitic structure is observed. Near the fusion line where the temperature exceeds A_3, there are some signs of grain growth. The fusion line between the base metal and 309L stainless steel is characterised by the presence of a light etching martensite which is in the form of a layer or band. The overlay consists of austenite and ferrite where the ferrite contents of 309L, 308L and 347 stainless steel layers are 9.4%, 9.3% and 10.5% respectively. The fusion boundaries between 309L and 308L and 309L and 347 can only be identified by the morphology of the ferrite grains.

In the unetched condition inclusions could clearly be seen uniformly distributed throughout the overlay. This is an inherent problem in submerged arc welding, however the inclusion size and distribution were similar to that reported in the literature (2,3,4,5). After stress relieving considerable changes were observed in the microstructures of HAZ and fusion line. In the HAZ, the bainite experienced tempering as is evident from the presence of a number of carbide precipitates Fig. 4. The martensitic band at the fusion line, as mentioned earlier, becomes easily visible. It becomes darker and wider. Many workers have attributed the easy visibility and darkness of martensite to the precipitation of carbides, (2,3,5). During stress relieving the carbon from the base metal migrates towards the fusion boundary and forms chromium carbides. This accumulation of extra carbides in the fusion zone is probably responsible for the widening of the dark band. The migration of carbon from the base metal leaves a decarburized zone just below the fusion line which can be seen in Fig. 4. Precipitation and accumulation of carbides along the grain boundaries of austenite can also be seen on the overlay side of the fusion line. This seems to have reduced the ferrite content of this region. Recently it has been reported that these austenite grain boundaries where carbide precipitation takes place are potential sites for hydrogen disbonding of the overlays (after prolonged exposure to the operating environment) during service (6).

The post weld heat treatment seems to have no noticable effect on the microstructures of the base metal or the overlays.

MICROHARDNESS SURVEY

Figure 5 shows the microhardness values in the overlaid joint. For the 'as welded' condition the hardness curve can be divided into four distinct zones. Moving from the base metal to the overlay the flat portion of the curve represents the uniform hardness of the base metal. In the HAZ the hardness gradually increases to a peak value of 350 DPH and then falls to about 315 DPH. This increase in hardness is caused by the increase in the amount of bainite as shown by the microstructures in Fig. 4. The peak hardness can be attributed to a fully bainitic microstructure in the HAZ. The drop in hardness after reaching a peak value is caused by the presence of coarser bainite. In the third zone marked as 'fusion zone', the hardness suddenly increases to about 400 DPH and then drops dramatically to about 200 DPH. This increase in hardness is because of the presence of a 'martensitic band'. Thereafter a drop in hardness occurs upon entering the overlay region. In the fourth zone (i.e., in the 309L, 308L, and 347 stainless steel overlay regions) the hardness remains relatively unchanged. All three overlays exhibited almost identical microstructures and hardnesses.

After stress relieving the hardness dropped in every zone, however, the relative drop varied from region to region. The greatest drop in hardness occurred in the HAZ and fusion zone which can be attributed to the tempering of bainite and martensite. In the overlay and base metal the drop (in hardness) is very small as no significant changes occurred in the microstructures of these regions. It is possible that this small change in hardness is from the release of residual stresses. A notable feature of the hardness curve after post-weld heat treatment is that the HAZ exhibits uniform hardness, similar to that of the base metal.

CHEMICAL COMPOSITION

The distribution of Cr, Ni, Mn, and Mo as determined by the microprobe analyser for the fusion and overlay regions of 'as welded' joints is shown in Fig. 6. It can be seen from Fig. 6 that on the overlay side the Cr, Ni, and Mn contents quickly rise over a distance of 100 μm. At the same time the Mo content falls. These values are maintained for the rest of the overlay. Though some variations in the Cr, Ni and Mn contents are noticed at

the fusion line between first layer and second layer, from a practical point of view these changes are insignificant. The narrow fusion zone and the uniformity of Cr, Ni, Mn and Mo contents thereafter indicates that the fused metal was completely homogenized. The chemical composition of the first layer also suggests that as far as Cr, Ni, and Mn requirements are concerned, they can be achieved in a single layer overlay by using 309L stainless steel strip. However, the use of single layer overlay is restricted because of its higher carbon content. It would be very useful to know the carbon distribution of the first layer, however, carbon is not easily measured by the microprobe analysis.

The complete analysis of the 308L and 347 layers as determined by the wet method, see Table 3, indicates that they meet the requirements of SFA 5.4.

CONCLUSIONS

An attempt has been made to clad 2.25 Cr - 1 Mo steel plates with 308L and 347 stainless steel by using a submerged-arc strip overlay process. A barrier layer of 309L stainless steel was used to counter the dilution effects from the base plate. The following conclusions can be drawn from the work reported here:

(i) The submerged-arc strip welding process can be used successfully to clad 2.25 Cr - 1 Mo steel with 308L and 347 stainless steels and defect free deposits can be obtained.

(ii) In the 'as welded' condition the microstructural constituents of HAZ, fusion line, and overlay are bainite and ferrite, martensite, and austenite plus ferrite respectively.

(iii) Tempering of martensite and bainite takes place during post-weld heat treatment which reduces their hardness.

(iv) Post-weld heat treatment has no significant effect on the microstructures of base metal and overlays.

(v) When subjected to guided bend testing, the overlay joints could be bent by 180° easily which indicates that they are ductile.

(vi) Composition requirements as specified in SFA 5.9 can be met in the 308L and 347 stainless steel overlays.

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REFERENCES

1. Chandel, R.S. and Hoare, R., "Effects of process variables on the bead geometry of the submerged-arc strip overlay welds"; Division Report MRP/PMRL 80-80(TR), CANMET, Energy, Mines and Resources, Canada; 1980.
2. Bush, A.F. and Calvin, P., Welding and Metal Fabrication 37:6:234; 1969.
3. Almqvist, G. and Egeman, N., (Ibid) 31:7:294; 1963.
4. Forsberg, S., Technical, "Practical and economic aspects of submerged-arc surfacing with strip electrodes"; Sandvik Lecture No. 91-34E, FSI; 1978.
5. Ohnishi, K., et al., Paper presented at the PVRC meeting, New York; September 1980.
6. Okada, H., et al. Paper presented at the American Society for Metals Conferences, Washington; 1982.

Table 1 - Chemical composition of materials wt %

Material	C	Mn	Si	P	S	Ni	Cr	Cu	Mo	Al	Nb	Ti	Ta	Ch	Co	
Base Metal CSA 387 Grade 22	.11	.48	.22	.011	.022	-	2.34	-	.95	-	-	-	-	-	-	
Strip 309L SS	.016	1.77	.42	.010	.003	13.15	23.55	.037	.03	-	-	.07	.01	.01	-	
Strip 308L SS	.014	1.78	.25	.007	.010	10.2	19.8	- .03	- .08	-	-	- <.01	-	- <.01	.02	N-0.31 V-.015 Mo-<.01
Strip 347 SS	.018	1.66	.35	.012	.009	10.1	20.3	.044	.07	-	-	-	-	-	Ta+ Cb-.61	

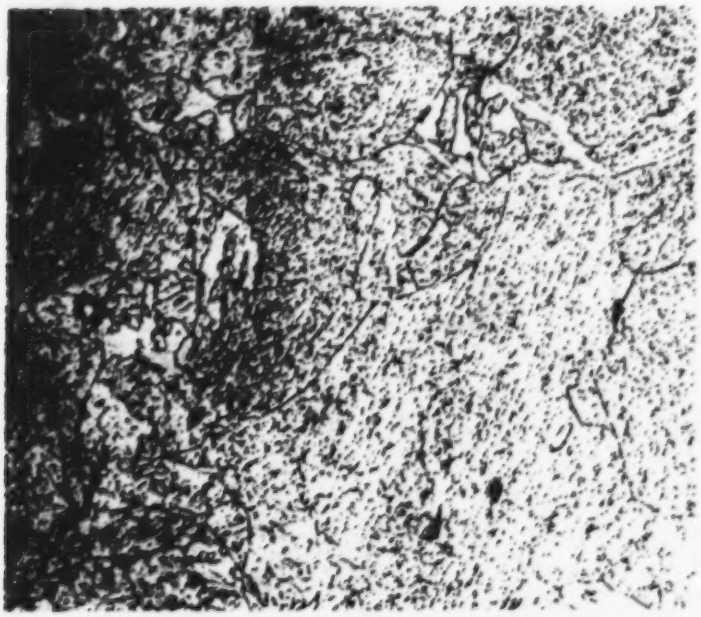


Fig. 1. Microstructure of parent metal, etchant - 2% nital. X500. (neg 8215)

Fig. 2. Cross section of a two layer strip-overlay weld. (neg 7204)

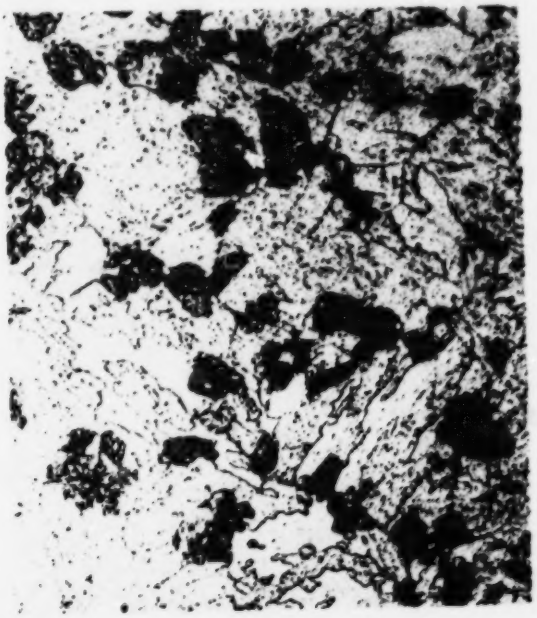
Fig. 3. Side bend test. (neg 7223)

Table 2 - Welding parameters

Parameter	1st Layer	2nd Layer
Current (A)	750	750
Voltage (V)	27	27
Travel Speed (mm/sec.)	2.33	2.33
E.S.O. (mm)	35	35
Polarity	DC+	DC+
Preheat Temperature (°C)	Room temp	Room temp

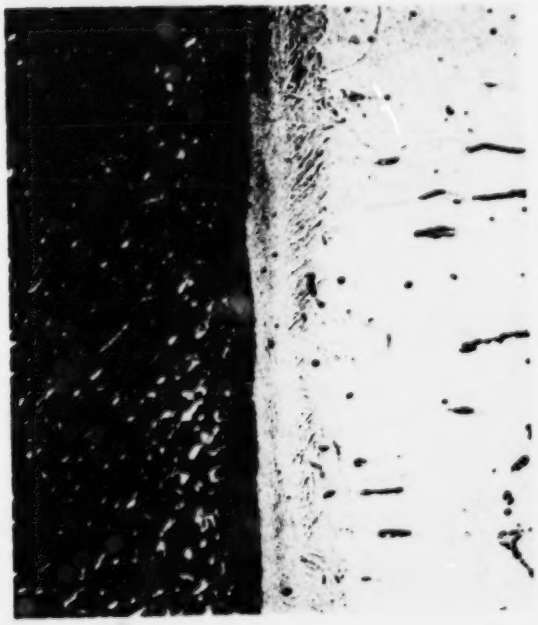
Table 3 - Chemical composition of the overlay at a distance of 2.25 mm from the surface (wt %)

Material	C	Mn	Cr	Ni	P	S	Cu	Cb
308L	.023	1.47	20.2	10.7	.009	.010	.029	-
347	.026	1.34	20.3	10.5	.012	.008	.044	.24

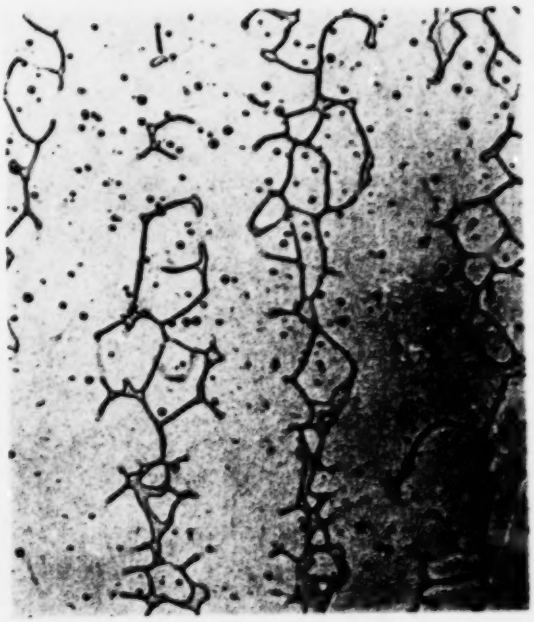


(a) HAZ - Away from the fusion boundary where the peak temperature during welding must have reached between A1 and A3. Etchant - 2% nital. X500 (neg 8217)

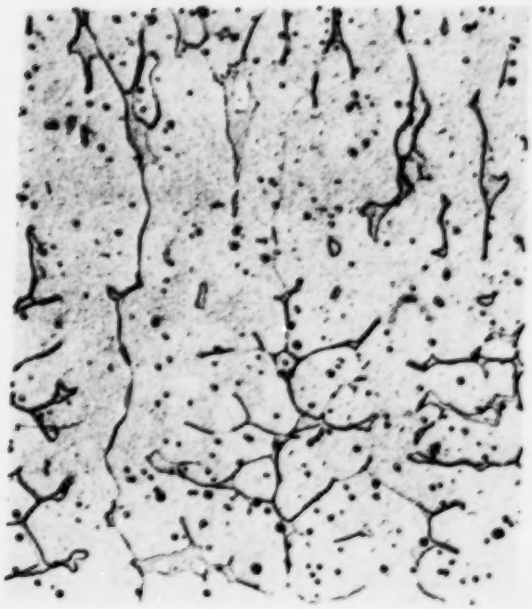
(b) HAZ - Close to the fusion boundary where the peak temperature during welding must have reached above A3. Etchant - 2% nital. X500 (neg 8216)



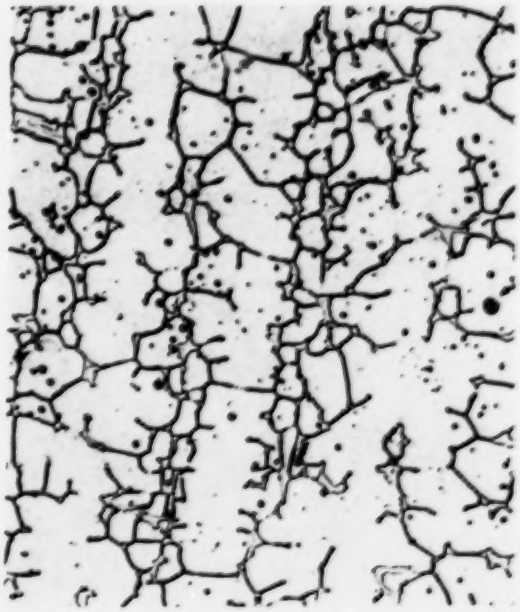
(c) Fusion zone between metal and 309L stainless steel. Etchant - 20% nital for base metal and 2% chromic acid for 309L stainless steel. X500 (neg 8213)



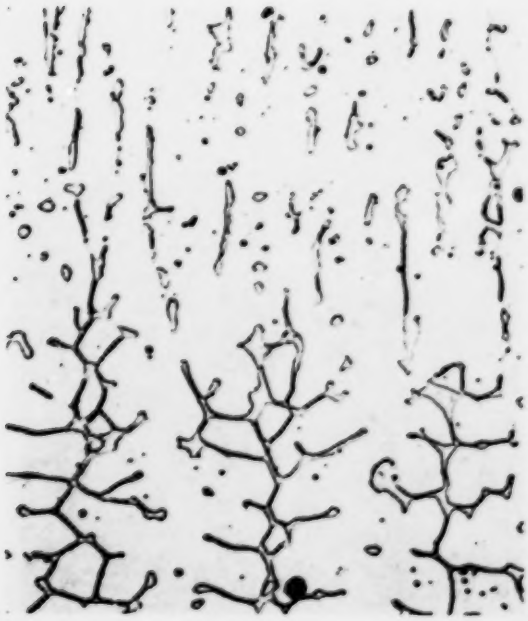
(d) 309L stainless steel. Etchant 2% chromic acid. X500. (neg 8214)



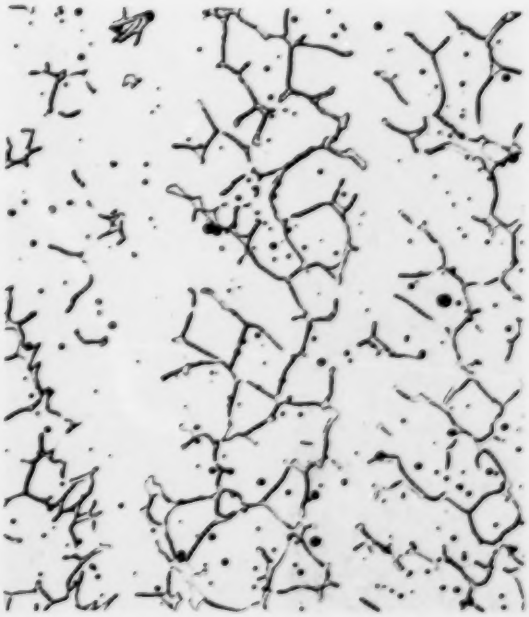
(e) Fusion zone between 309L stainless steel and 347 stainless steel. Etchant - 2% chromic acid. X500 (neg 8212)



(f) 347 stainless steel. Etchant 2% chromic acid. X500 (neg 8211)

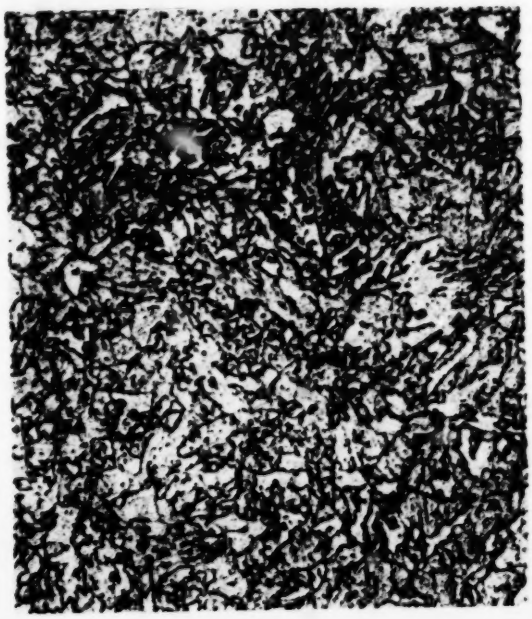


(g) Fusion zone between 309L stainless steel and 308L stainless steel. Etchant 2% chromic acid. X500 (neg 8210)



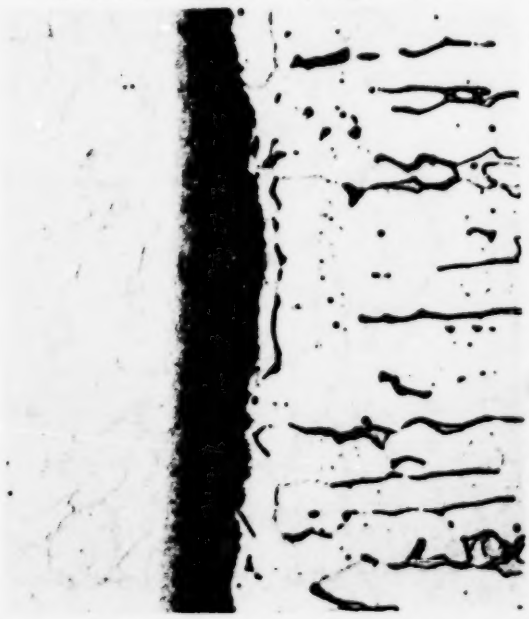
(h) 308L stainless steel. Etchant 2% chromic acid. X500 (neg 8209)

Fig. 4. (a-h) Microstructures of 'as welded' overlay joint.



(a) HAZ - Away from the fusion boundary where the peak temperature during welding must have reached between A1 and A3. Etchant - 2% nital. X500 (neg 8208)

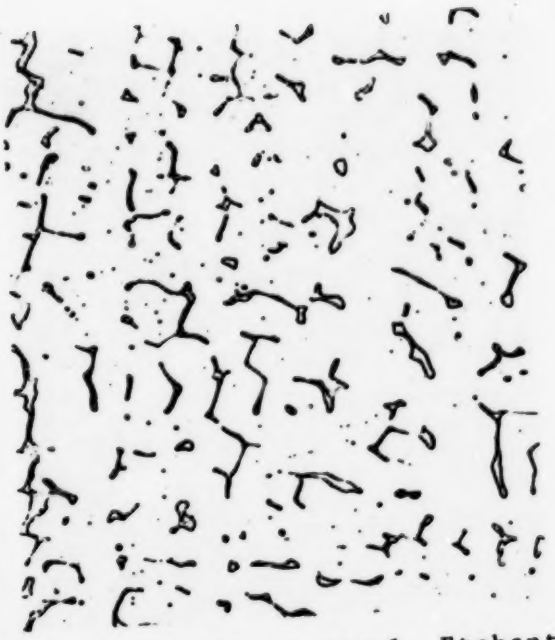
(b) HAZ - Close to the fusion boundary where the peak temperature during welding must have reach above A3. Etchant - 2% nital. X500 (neg 8207)



(c) Fusion zone between base metal and 309L stainless steel. Etchant - 2% nital for base metal and 2% chromic acid for 309L stainless steel. X500 (neg 8203)

(d) 309L stainless steel. Etchant 2% chromic acid. X500 (neg 8206)

(e) Fusion zone between 309L and 347 stainless steel. Etchant - 2% chromic acid X500. (neg 8202)

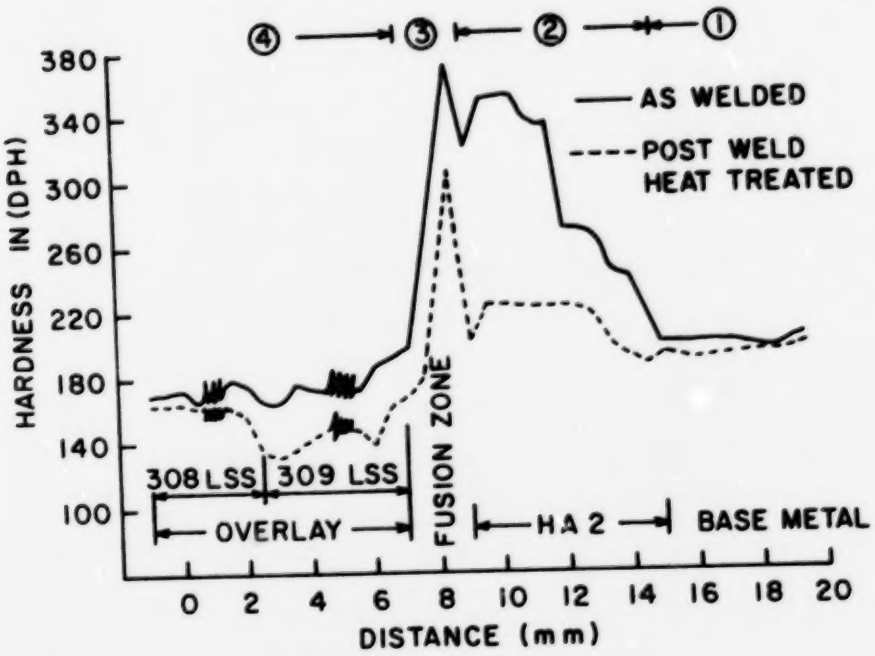


(f) 347 staihless steel. Etchant 2% chromic acid. X500 (neg 8218)

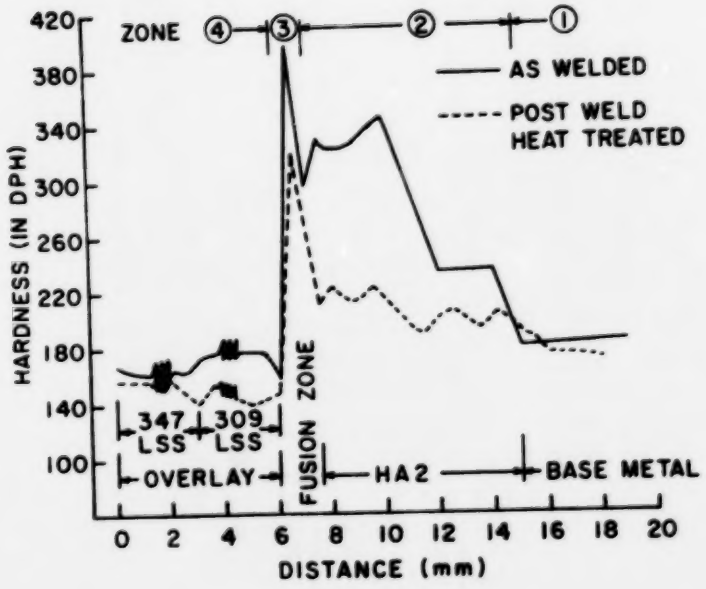
(g) Fusion zone between 309L and 308L stainless steel. Etchant 2% chromic acid. X500. (neg 8205)

(h) 308L stainless steel. Etchant 2% chromic acid. X500. (neg 8204)

Fig. 5. (a-h) Microstructures of 'stress relieved' overlay joint.

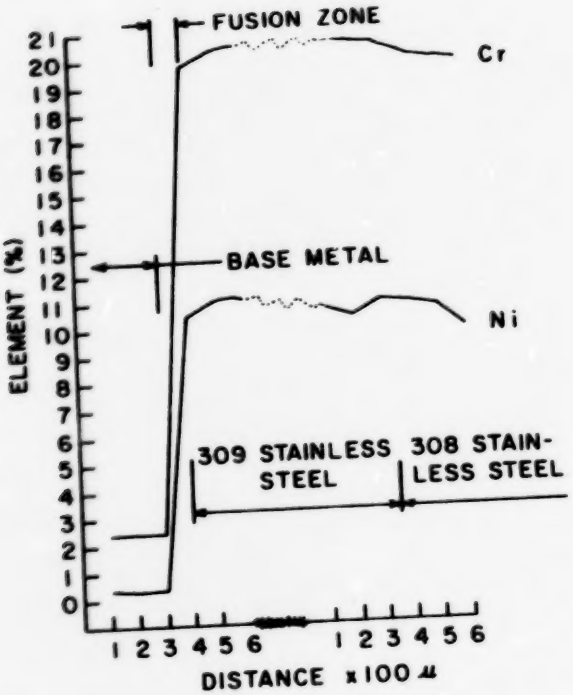


(neg 8300)



(neg 8301)

Fig. 6. Microhardness distribution in a strip overlay joint.



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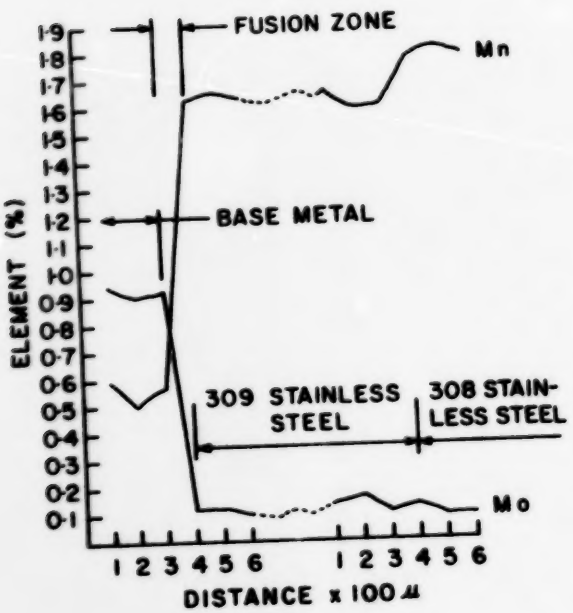

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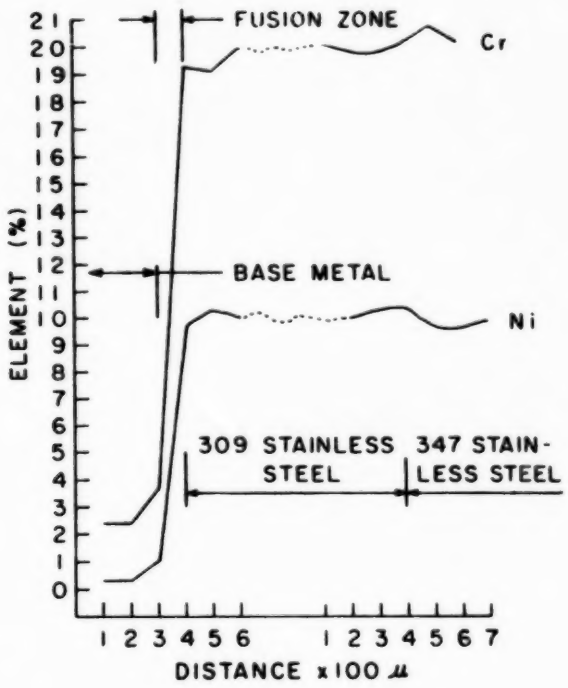
Fig. 7. cont'd.



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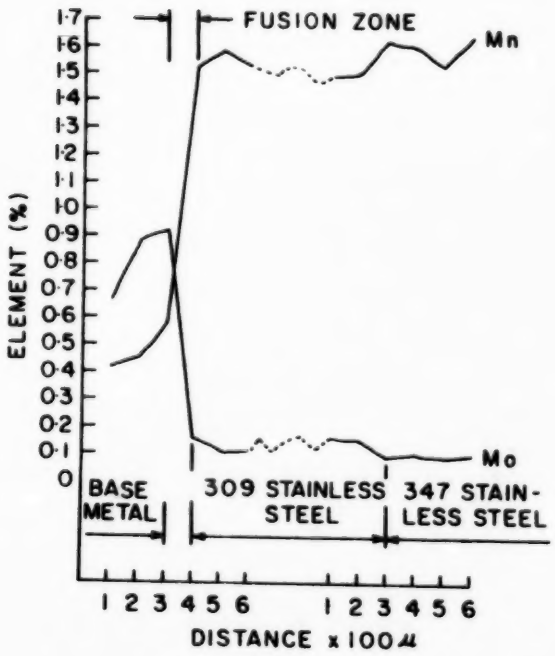

(neg 8302)

Fig. 7. Cr, Ni, Mn and Mo contents of the overlay as a function of distance (as welded).

POOR

QUALITY

ORIGINAL